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SOME UNUSUAL EROSION FEATURES IN THE LOESS OF CHINA

BY MYRON L. FULLER

The general characteristics of the landscape of the yellow earth region of northern China are well known. The deep sunk valleys and deep worn roads, the vertical walls with their excavated dwellings, the natural terraces perforce figure in any description of "loess land." It is here proposed to discuss some of the minor forms exhibited by the loess.

Natural Loess Bridges

Of the several striking forms resulting from loess erosion none is more conspicuous than the natural bridge. In general aspect (Fig. 1) the natural bridge of the loess closely resembles the familiar limestone bridge. The span of the arches seldom exceeds half the height of the opening: broad spans, such as those of the sandstone arches of Utah, are naturally unknown in a material which is unconsolidated, uncemented, and of limited cohesion.

Loess bridges are natural in their mode of formation, although certain artificial conditions, such as artificial terracing, may favor their development. They are invariably found near some abrupt change of slope, as along the rim of a ravine or canyon-cut plateau, near the edge of a flood plain, or on the interrupted slopes of terraced hillsides. A few have also been developed in the divides between headward-advancing ravines, whose upper ends are approaching each other.

The loess bridges, because of the limited cohesion of their material, are necessarily short-lived as compared with limestone and sandstone bridges; but weathering and erosion features associated with them seem to point to ages measured by hundreds of years, if not occasionally a thousand. They never span flowing streams but are limited to gullies in which water flows only after fairly heavy showers.

LOESS BRIDGES ON PLATEAU RIMS

Loess bridges occur most commonly on plateau rims. They are found where the waters of the flat or gently sloping upland surfaces find downward passage along the vertical joint, cleavage, or other structural planes of the loess, to relatively porous bedding planes, thence laterally to adjoining ravines. The passages, through combined spalling, caving, solution, and mechanical dissolution of the walls, become rapidly enlarged into vertical pipes or wells connecting with, or merging into, horizontal or

downward sloping tubes. Figure 2 is a view taken from the inside of such a tube, in this instance some three feet in width and ten feet in height, looking outward toward the valley into which it drains.

The next step in the process is the formation of other pipes and tubes along the line of drainage in the rear of the first (these later caving to form an open gully) or the eating back of the loess by the normal process of gullying. In the meantime the covering above the tubes is reduced, while

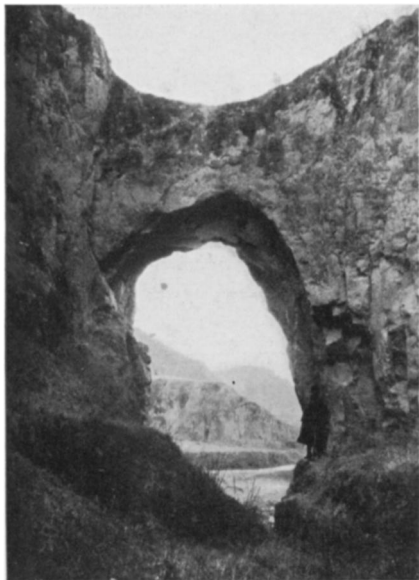


FIG. 1—Loess bridge spanning the mouth of a ravine.

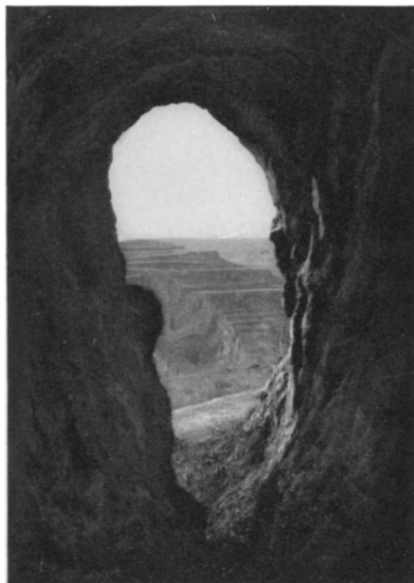


FIG. 2—Looking outward from a loess tube connecting loess well or sink with valley.

the tubes are enlarged until, in the end, natural bridges alone remain spanning the gullies, which may lead backward into the uplands as open cuts half a mile to a mile or more above the arch. Figure 1 shows a good example of this type of bridge. A smooth, grassy remnant of the plateau constitutes the top. On the sides, at the level at which the man is standing, are shelves marking a former position of the floor beneath the arch, now cut to a depth of five to eight feet by a sharp V-shaped notch, as a result of the rejuvenation of erosion. The breadth of the arch is about 15 feet and its height about 35 feet above the bottom of the notch. The opposite hills rise to heights of 300 to 500 feet and are entirely of loess. The characteristic jointing, which so facilitates the penetration of water, is seen on the right.

LOESS BRIDGES ON TERRACED SLOPES

The artificial terracing of valley sides as an aid to cultivation presents conditions particularly favorable to the formation of loess bridges. The

normal run-off is checked both by the flat steps and by the raised rims which enclose the terraces on the outer sides, with the result that the water has a more than ordinary tendency to follow the perpendicular plains downward into the loess and thus to the formation of vertical pipes and connecting tubes and, eventually, the development of natural bridges as out-

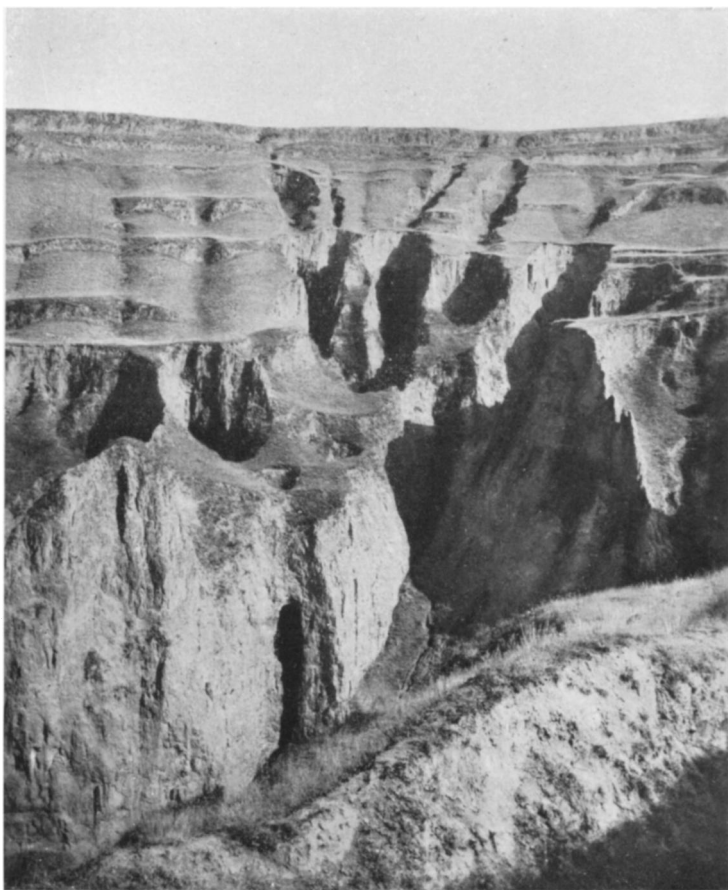


FIG. 3—Loess pipes, tubes, wells, and sinks on terraced slope.

lined above. Figure 3 shows the earlier stages of bridge formation on a terraced slope. In the foreground is the mouth of a tube, similar to that of Figure 2, draining the two small pipes immediately above as well as the larger loess well in the rear. In the center, to the right and somewhat above the foregoing, is an older, much enlarged, irregular well draining outward under a bridge into the ravine within the dark shadow on the right. Above this big well or sink, in turn, entering it beneath bridges in shadow, are three open gullies leading back to the edge of the plateau. As in the case

of the plateau bridges, the water movements concerned take place far above the normal ground-water level. Details of the subterranean erosion of the loess are more fully discussed in the section on loess wells.

LOESS BRIDGES ALONG STREAMS

The bridges along streams are not formed above the water table, as were the bridges previously described, but are the result of normal ground-water movements, through which parts of the loess are mechanically removed and borne to the stream toward which the waters drain. The result of this undermining is a series of jagged gash-like sinks, often paralleling the river for some distance, as shown in Figure 4. In the walls between the gashes and the streams a number of loess windows and bridges are usually found; but they are short-lived, the walls soon crumbling by the mechanical erosion of the supporting loess. No instance of the formation of a bridge by normal undercutting was observed.



FIG. 4—Loess gash sinks paralleling a stream.

BRIDGES OF FLOOD PLAINS AND DIVIDES

In the loess regions of China the flood plains of the streams are mainly composed of eroded, transported, and redeposited loess, which, in the absence of sand, gravel, or organic material (the latter rare under the existing arid conditions) is indistinguishable from wind-deposited loess. The wet-weather drainage across such flood plains has occasionally produced bridges of six to ten feet in span and ten to fifteen feet in height, under conditions essentially similar to those described above.

When two complexly branching and opposing stream systems cut backward in the thick loess, it is inevitable that individual gullies will occasionally head against one another. In many cases where the erosion has been rapid, the gullies terminate in vertical walls. Under such conditions the bottoms may be cut through while the tops are still preserved, leaving natural bridges of varying span and height.

DISTRIBUTION OF LOESS BRIDGES

Loess bridges are characteristic of youthful stages of erosion and are limited, so far as the writer's observations go, to those regions where there



FIG. 5



FIG. 6

FIGS. 5 and 6—Loess dikes between the heads of opposing streams. Both examples occur on important routes and show evidence of artificial maintenance.

has been increased erosion following recent rejuvenation. This rejuvenation may be due to the supposed recent deforesting of the loess area by man, to an increase in average rainfall, or to differential elevation of the loess area. The first cause is regarded by the writer as doubtful in most cases. The last, which is borne out by many features of the loess topography itself, as well as by certain features of the rock valleys of the Hwang Ho and tributary



FIG. 7.—Loess dike forming the divide between two streams eroding unequally—one (to the left) rapidly, the other (right) slowly.

streams, is regarded as the most probable cause of the accelerated erosion and the formation of the loess bridges. The examples illustrated are all on tributaries of the Hwang Ho in eastern Shensi.

Loess Dikes or Wall Divides¹

The traveler in the more deeply dissected portions of the loess is certain to retain vivid impressions of the dizzy heights of the narrow, vertical-sided dikes which constitute the wall-like divides between the heads of opposing ravines.

The dikes are usually fairly straight,² but a few are curved or even

¹ The name wall divide has been suggested by W. M. Davis and D. W. Johnson.

² Compare the illustration, Figure 4, of F. G. Clapp: *The Hwang Ho, Yellow River*, *Geogr. Rev.*, Vol. 12, 1922, p. 8. Several photographs have been loaned for use in this paper by F. G. Clapp.

sinuous (Fig. 5). Their faces, in the central portions at least, are nearly or quite vertical and from 50 to several hundred feet in height. Connecting the plateau levels on either side, they form natural passageways which have been utilized by the Chinese from time immemorial in their travel on foot or mule. They are seldom over ten feet in width, often no more than five feet, and the views of the depths below from the backs of horses or mules are found by many disturbing if not actually terrifying. Indeed, even the natives often dismount on the narrow dikes and sometimes actually crawl across on hands and knees. Nor is the danger entirely imaginary, for after protracted rainless seasons the loess becomes exceedingly dry and considerable masses not infrequently scale from the sides, sometimes precipitating mules and even men into the depths below. Some of the dikes traversed by the writer's associates in China had dwindled to a width of less than a foot and crumbled even as the mules passed. Since their use saves descents of many hundreds of feet into the precipitous ravines and heartbreaking climbs back to the plateau levels on the opposite sides, they are never abandoned as long as a mule can scramble across.

While the sides of the dikes are characteristically vertical, their attitude is really dependent upon the rapidity of backward erosion. Where the streams on either side of the divide are eating back slowly, the walls may not have angles of more than 45° . When one is eroding slowly and the other more rapidly, the walls may be respectively sloping and vertical, as on the right and left sides of Figure 7. With rapid erosion on both sides, each wall is vertical.

The lengths of the narrow portions vary from a few rods to several hundred feet, but the approaches are often over narrow spurs of much greater length (Fig. 5).

FORMATION OF THE DIKES

The primary causes leading to the formation of loess dikes are definite and simple, being normal headwater stream erosion acting on a soft material with vertical jointing or at least a marked tendency toward vertical scaling.

Why the dikes are so long and so straight is not so clear. The straightness and smoothness of the sides often give an appearance of artificiality, but in only a few instances was any actual evidence of the hand of man recognized. The most conspicuous examples of artificially maintained dikes are shown in Figures 5 and 6, the first on an important trail near Chung Pu;³ the second on the main cart road of north Shensi near Lo Chwan. The smooth sides of both give unmistakable evidences of human workmanship. Figure 7, on the other hand, shows a dike which appears to be untouched by man. In the case of one or two of the smaller dikes it was observed that brush had been placed to retard the wash.

³See the map "The Great Wall of China," *Geogr. Review*, Vol. 9, 1920, opposite p. 268.

It is evident in many instances that the opposing ravines, having cut back to within a few feet of one another, begin to broaden out on both sides, instead of cutting through the narrow separating walls. The high, narrow dikes may indeed remain while gullies are cut back laterally, perhaps for hundreds of feet. The prevailing straightness of the dikes suggests a relation between their form and the use to which they have been put by man. Possibly the compacting of the tops under the feet of travelers, who commonly outnumber the mules or donkeys, makes the surface more



FIG. 8—Erosion pinnacle in normal loess.



FIG. 9—Turret pinnacle in aqueous loess and gravel.

resistant to the penetration of rain and scaling, or the lateral ditching along lines later followed by side gullying may aid in determining the form of the dike. Both suggestions seem far-fetched, but the fact remains that the erosion actually takes place as described and leaves the long, straight, high divide walls or dikes.

Loess Pinnacles

Loess pinnacles, standing as detached tower-like or needle-like masses, are not uncommon features of loess erosion in China. In origin the loess pinnacles may be either wholly natural or the result of a combination of natural and artificial conditions. They may take the shape of turrets, spires, sharp cones, thin, finlike masses, or of combinations of two or more of these forms. The material is usually pure loess but may be a mixture of sand and gravel with reworked (aqueous) loess.

TURRET PINNACLES

Flat-topped turrets of pure loess are rare, for the reason that the caps of such pinnacles, consisting of loess which has lost its normal cohesion through its conversion into soil and the penetration of rootlets, do not long preserve their vertical faces but rapidly scale away at the sides until their terminations become mere points. Such an example is illustrated in Figure 8, which shows a pinnacle about 40 feet in height and 13 feet in diameter. A pinnacle of this form may be regarded as transitional between turret and spire. The true turret form is shown by the gravel and loess pinnacle of Figure 9.

The turret pinnacle is practically always the result of normal natural processes of erosion. In the majority of instances, the loess masses first become detached as a result of the differential retreat toward one another of the vertical loess walls of the V-shaped points between valleys joining at acute angles. The severed bodies that result are triangular, rounded, or irregular in outline and may be of considerable size. They suffer slow reduction mainly by the spalling of slabs from their vertical faces. Sharply projecting points not infrequently become severed from irregular loess cliffs and by the same process are converted into turret pinnacles, or again they result from the reduction of masses detached by cut-offs of broadly swinging streams; but these last are not common.

SPIRE AND NEEDLE PINNACLES

Spire and needle pinnacles have the general form shown in Figure 8, but they are more slender and needle-like, with diameters only a small fraction of their heights. In 8,000 miles of traverse only a few were seen, and these under conditions which did not permit them to be photographed. An idea of the form of such needles or spires may be gained by imagining the left portion of the pinnacle of Figure 8 to be split away along the line of separation already seen to be developing, leaving the slender right section standing alone. Such pinnacles are usually not over twenty or twenty-five feet in height and three to five in diameter. They are probably most frequently the result of the scaling of masses from cliffs. The beginning of the separation of such a spire is shown on the right side of the loess canyon of Figure 10. Since this separation is the result of movements of the detached portions themselves rather than the removal of material in their rear, there must be a certain crushing or movement of the material of their own bases which largely destroys the natural coherency of the loess. For this reason, the spires produced by this type of spalling are weak and short-lived.

CONICAL PINNACLES

The conical pinnacle is a steep-sided, usually slightly blunted, cone of loess having a height from one to two times its diameter. An example is

shown in Figure 11 which has an approximate height of 50 feet and a diameter of 30 feet, a size above the average, for the majority of the forms that may properly be regarded as pinnacles do not exceed 30 feet in height or 20 feet in diameter. Conical pinnacles result from the same natural processes as in the case of the turret pinnacles and also in considerable number from partly artificial conditions. The soft loess of the roads and trails is churned up by the wheels of carts or the hoofs of mules until a bed of loose dust six inches to a foot or more deep is formed. This is either picked up by the wind and whirled away or washed out to some near-by valley by rain. Sometimes several inches is removed during a single storm.



FIG. 10—Beginning of separation of spire pinnacle from loess cliff.

and the road or trail gradually becomes a miniature canyon. Many are now 50 feet in depth, and some 75 to 100 feet or more, though most are abandoned before reaching the latter depth. In a large number of instances new roads are started close to the rims of the old ones, and, as they in turn are worn down, parallel canyons, separated by thin loess walls, result. By the natural processes of scaling and spalling, the walls are slowly broken down and a series of cones, spires, or fin pinnacles remains to mark the points where they were thickest. The conical pinnacles thus formed, many of which mark roads abandoned hundreds or even a thousand years ago, far outnumber those formed by purely natural erosion. Figure 11 shows two residual pinnacles of this origin. In this instance, three lines of former road at two levels are involved, while as many others skirt the rims outside the limits of the picture, which shows one of the oldest roads of Central China, possibly dating back to 2000 B. C. There is reason to believe that

many of the loess-canyon systems, although now showing no trace of roads, had their inception in the wear and wash of ancient highways.

FIN PINNACLES

The fin pinnacle is a tall, thin, elongated, flat-sided mass of loess with notched crest, suggesting in its general form the dorsal fin of a fish. The central mass of Figure 12 represents a pinnacle of this type. The height is 40 or 50 feet, and the thickness five or ten feet. Fin pinnacles are rarely the result of normal erosion. It is conceivable that under especially favorable conditions they may originate between two closely adjacent streams or at the necks of oxbows, but no examples of either were noted. The great majority of those seen represented broken-down partings between ancient double roads.

Another important class is that formed by a similar process along the rims of cliffs. In those parts of China where the intense struggle for a living compels the utilization of every possible inch of tillable land, the upland roads and trails are crowded, wherever possible, to the very edge of the cliffs bounding the plateau remnants. As such roadways become worn down, narrow loess walls remain between them and the cliff faces and in the process of gradual reduction give rise to numerous fin pinnacles.

DISTRIBUTION OF PINNACLES

The pinnacles do not seem to be limited to any particular locality, providing the loess sheet is of sufficient thickness to permit their development, and they may be looked for anywhere in the great loess area lying between the Mongolian, or Gobi, Desert on the north and the mountains of southern Shensi on the south, and between the Coastal Plain on the east and undetermined limits in western Kansu or beyond. There seems to be a more marked tendency toward the formation of pinnacles in comparatively humid Shensi and Honan than in the more arid Kansu. Few were seen in Shansi, possibly because of the comparative thinness of the general loess sheet, partly because of less sharply developed erosion and the prevalence of more gentle slopes, and partly owing to the greater precautions taken against gullying on the part of the more numerous inhabitants.

Loess Wells

A loess well is a circular hole of varying size and depth closely resembling in appearance an ordinary well dug for water before it has been stoned up (Fig. 13). The usual diameter of the wells seen was eight or ten feet, but occasional diameters as small as five feet or as great as 20 feet were noted. The wells were never less than 15 feet in depth and seldom more than 30 feet. The walls were vertical for practically the entire depth. Bottoms were cup-shaped or irregular and usually deeper on the far side with refer-



FIG. 11



FIG. 12

FIGS. 11 and 12—Loess pinnacles left by the erosion of ancient parallel roads. Figure 11 shows a conical, Figure 12 a fin pinnacle.

ence to the direction of ground-water movement. In some instances openings a foot or two in diameter, occasionally larger, led away from the well in the same direction.

All the typical loess wells seen by the writer were in the eastern portion of the province of Kansu, about 600 miles southwest of Peking. None were encountered in Shansi or Shensi, although both provinces, which are deeply loess-covered, were crisscrossed from north to south and east to west by numerous traverses. Each of the latter provinces afforded, however, instances of irregular tubes and gashes apparently of the same origin as the circular wells, and it is to be supposed that wells also occur.

The loess wells always occur on flat upland surfaces of the general loess plateau not far removed from gullies, ravines, canyons, or deep valleys where walls are vertical or at least very steep. Probably few wells are found more than 150 feet from the plateau rim, while most are within 100 feet of it. They are not associated with surface depressions but are formed on flat surfaces like that shown in Figure 14.

The loess wells are clearly of the nature of sinks, but they result primarily from settling consequent upon the mechanical removal of underlying material rather than from its removal by chemical action as in ordinary limestone sinks. Their inception seems to result from seepage movements, sometimes along bedded layers, which, although differences are indistinguishable to the eye, are, nevertheless, more porous than the surrounding material; but more frequently they result from water movements along irregular channels leading diagonally downward through the loess toward an adjacent ravine or valley at angles of 30° , 45° , or even 60° . They are entirely above, and unconnected with, either normal or perched ground-water tables and represent simply the lines of least resistance to percolating waters.

The water movement along such lines probably results in some solution of the calcareous particles of the loess but leads first to increased porosity rather than to open passages. Soon, however, the openings along the line of movement become large enough to permit the mechanical transportation of the finer particles of the loess; and more or less tubular channels, analogous to those giving rise to the springs of clays and glacial tills, are formed. Eventually, by the caving of roof and walls, these may reach diameters of a foot or more. Wherever, along such passages, the well-known tendency of the loess to vertical cleavage happens to be most strongly developed, caving from the roof will begin on a more conspicuous scale. Downward percolation of waters from the surface furthers the process, and perpendicular cylindrical cavities will be extended upward, finally reaching the surface and giving typical loess wells.

In dry times the drainage passages tend to close by spalling or caving but they are reopened after heavy rains. By progressive enlargement the areas between the wells and the mouths of the outlet are undermined until, in the end, ravines heading at the wells replace the underground passages.



FIG. 13



FIG. 14

FIG. 13—Natural wells in loess on the plateau surface near a canyon rim.

FIG. 14—Typical loess plateau, near the rim of which the natural wells are developed.

In at least one instance a loess well has been known to result from the caving of an abandoned underground dwelling dug into the face of a cliff 30 feet or more below the surface in which the well was developed.

There is no definitely known cause of the limitation of the wells to the Kansu area. Possibly the reason lies in the more calcareous nature of the Kansu loess, which is nearer its source, Mongolia, and has been largely a direct deposit of the wind, while to the south and east water transportation intervened before the final distribution of the loess by winds. The greater rainfall in Shansi and Shensi may also favor the formation of large gashes and irregular cavities rather than the smaller and more symmetrical wells, while the latter, if formed, might be sooner destroyed by the more copious rainfall.